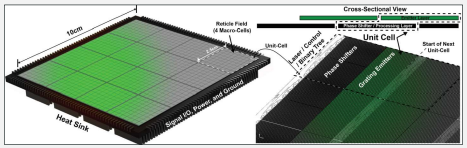
# Modular Optical Aperture Building Blocks (MOABB)

Christopher V. Poulton, Matthew J. Byrd, Peter Russo, Erman Timurdogan, Michael Whitson, Ehsan Hosseini, Benjamin Moss, Zhan Su, Diedrik Vermeulen, and Michael R. Watts (CEO)

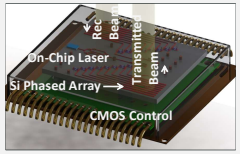
Analog Photonics

## Driving Applications: Solid-State Beam Steering, Chip-Scale LiDAR, and Free-Space Communications

### Program Goal

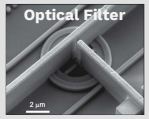


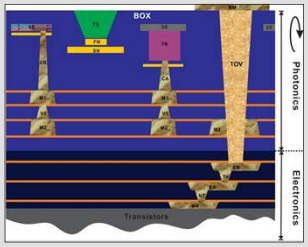

| Specification | Phase I BAA | Phase II BAA | Phase III BAA |
|---|---|---|---|
| Aperture Size | $1mm^2$ | $1cm^2$ | $10cm^2$ |
| P-P Sweep Time | 40us | 10us | 1us |
| Field of Regard | 70°x12° | 100°x14° | 110°x16° |
| Aperture Fill Factor | 50% | 70% | 95% |
| # simultaneous beams | 1 | 16 | 16 |
| RF Bandwidth | 3 GHz | 8 GHz | 8 GHz |
| Wall-plug Efficiency | 1% | 2% | 5% |
| Radiated Power Density | $0.5W/cm^2$ | $0.5W/cm^2$ | $1W/cm^2$ |
| % Optical Power in formed beams | 50% | 80% | 95% |

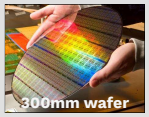


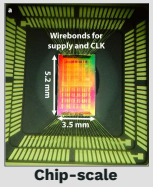

- The MOABB program aims to create a large integrated flat optical aperture with a $10cm^2$ area
- Based on tiling smaller unit-cell optical apertures
- Enables high-power optical beam transmitting and receiving with solid-state beam steering

### Integration Platform



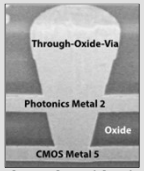




Chip-scale photonic systems

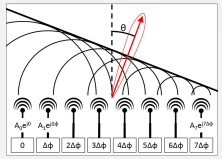

3D wafer bonding




Through-oxide via

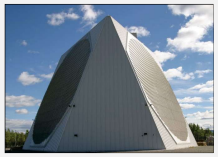
- Silicon photonics is a chip technology enabling optical "circuits" based on laser light guided in silicon optical nanowires.

### Optical Phased Arrays

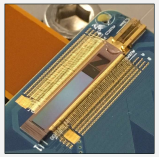



$$E_{tot}(\theta,\phi) = \underbrace{E(\theta,\phi)}_{\text{Element Factor}} \times \underbrace{\sum_{n=0}^{N-1} A_n e^{j(kr_n\cos\theta+\psi_n)}}_{\text{Array Factor}} \sim E(\theta,\phi)\frac{\sin(N(kd\cos(\theta)+\alpha)/2)}{\sin((kd\cos(\theta)+\alpha)/2)}$$

RADAR Phased Array

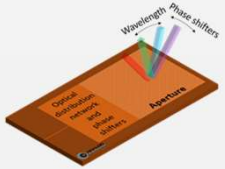


Optical Phased Array

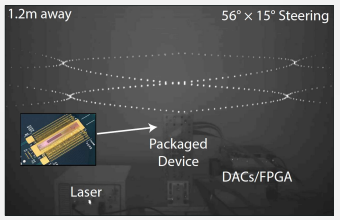


- Phased arrays are arrays of electro-magnetic antennas with individual phase control
- Tuning the phases allows for arbitrary pattern generation and beam steering

### 2D Beam Steering

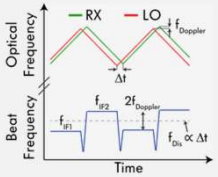




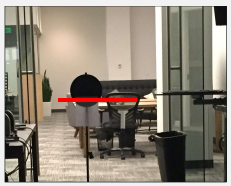


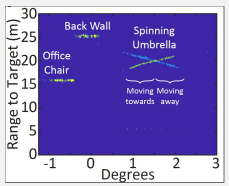

- 2D beam steering is achieved by utilizing element phase shifters and changing wavelength
- Steering ranges up to 70° x 18° have been demonstrated with pitches down to 1.35um

### Integrated FMCW LiDAR




- Frequency-modulated continuous-wave laser
- Distance is proportional to electrical beat frequency
- Coherent detection amplifies signal, allows for modest photodetectors

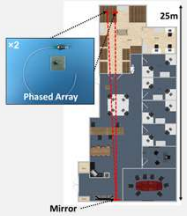


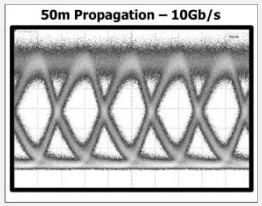



- Coherent LiDAR system created with two passive OPAs
- Up to 40m real-time LiDAR demonstrated
- Doppler extraction realized in order to measure the velocity of targets

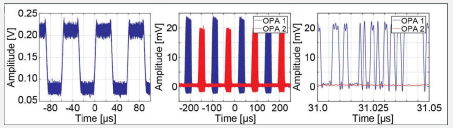
### Free-Space Communication

#### Passive OPAs



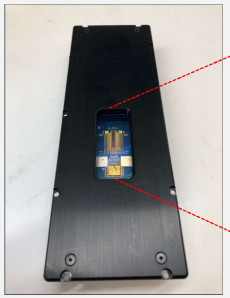



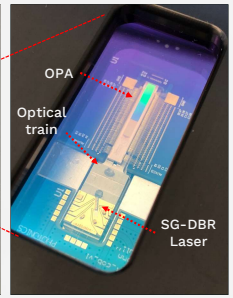

#### Active OPAs




- 50m free-space data link achieved at a 10Gbps data-rate with two passive optical phased arrays as a transmitter and a receiver
- Active demo of OPA-based free-space communication successful with beam steering between two receivers (1Gbps at 1m)

### Laser Integration

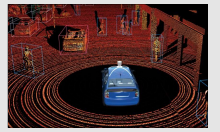





- The high integration of silicon photonics allows for co-packaging with an integrated III/V laser
- Above shows an optical phased array chip co-packaged with a III/V sampled grating distributed Bragg reflector (SG-DBR) laser
- Optical coupling between the two chips is realized with two ball lenses that performs mode-matching between the two couplers

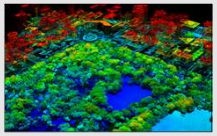
### Applications

#### Automotive



#### Robotics

#### Aerial Vehicles



Contact: Michael R. Watts (CEO) | mwatts@analogphotonics.com



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